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DIGITAL COMPUTER PROGRAM FOR THE ANALYSIS OF CRACK PROPAGATION IN CYCLIC LOADED STRUCTURES

R. G. FORMAN
J. P. HUDSON

TECHNICAL REPORT AFFDL-TR-67-5

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AIR FORCE FLIGHT DYNAMICS LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
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FOREWORD

This report was prepared by the Directorate of Computation, Systems Engineering Group, Wright-Patterson Air Force Base (WPAFB), Ohio and the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio. The work was conducted under Project 1467, "Structural Analysis Methods", Task 146704, "Structural Fatigue Analysis", with Mr. Robert M. Bader acting as Project Engineer.

Mr. Royce G. Forman, Air Force Flight Dynamics Laboratory, prepared the theoretical part of this report. Mr. J. P. Hudson, Systems Engineering Group, performed the programming of the analysis and assisted in writing the description of the computer program.

The use of the computer program described herein can be obtained by contacting AFFDL (FDTR/Mr. R. G. Forman), Wright-Patterson AFB, Ohio 45433.

The manuscript was released by the authors in December 1966 for publication as an RTD Technical Report.

This technical report has been reviewed and is approved.

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ABSTRACT

This report presents a detailed description of a computer program for analyzing crack propagation in cyclic loaded structures. The program calculates crack growth, both for uniform and non-uniform cyclic loading and also calculates the number of load cycles to cause instability of crack growth. Instructions for use of the program and two illustrative analysis problems are presented.

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LIST OF SYMBOLS

A	crack length dimension
AI	initial crack length dimension
B	a geometrical dimension of the problem; e.g. plate half width or hole radius
C	material constant for crack propagation
K	A/B, ratio of crack length to plate width
DK	stress intensity factor range in a load cycle
KC	fracture toughness parameter
P	applied load (or stress) on a plate
DP	range of applied stress in a given cycle; e.g. maximum stress - minimum stress
R	minimum applied stress/maximum applied stress
T	cycle number
TI	initial cycle number
TF	final cycle number in a block load
SN	power of DK
DT1	printout interval for T
f( )	a function of
dA/dT	crack extension per cycle
β	plate width correction factor

SECTION I

INTRODUCTION

The computer program presented in this report was developed to support in-house research efforts by the AF Flight Dynamics Laboratory in crack propagation analysis of cyclic loaded structures. The program was specifically written to take into account complex crack geometries and cyclic loads of nonuniform character. The generality of the program and the simplicity of input data were achieved by writing and running the program under the digital simulation program MIMIC. The program in its present form was found very useful in solving numerous problems occurring in aircraft type structures, such as fatigue crack propagation and crack growth emanating from projectile impact damage.

SECTION II

DESCRIPTION OF COMPUTER PROGRAM

This program calculates the crack propagation behavior of cyclic loaded structures by means of the theory described in Reference 1. The theory states that the crack growth rate is governed by the following first order linear differential equation:

$$\frac{dA}{dT} = \frac{C(DK)^{SN}}{(1-R)KC-DK} \tag{1}$$

For problems of cyclic load of uniform character, e.g. the load range, DP, and the load ratio, R, constant, equation (1) has the form

$$\frac{dA}{dT} = f(A) \tag{2}$$

Given an initial crack size at an initial value of T, such as T = 0, the computer program calculates the crack length after a given number of cycles. The program also calculates the number of cycles required for crack growth instability, or the point when the denominator in equation (1) first becomes negative.

The program was written in MIMIC, a Digital Simulation Program developed at Wright-Patterson AFB, and was run on an IBM 7094/7044 DCS Computer with a Fortran IV IBSYS monitor. Thus, this program may be run at any installation which has the capability of processing MIMIC programs. The MIMIC program is available on request (see reference 2) and has been written for a number of computers.

Input to the crack propagation program includes the following parameters for all problems to be analyzed:

AI	Initial value of A
C	Material constant
SN	Power of DK
KC	Fracture toughness parameter
DT1	Printout interval for T
TI	Initial cycle number

Other parameters, such as the plate width, B, are usually required, but they will depend on the particular problem to be solved.

In addition, the function representing the stress intensity factor range, DK, must be defined. The function can be expressed analytically, or it can be listed as point values in tabular form.

For example, many solutions for DK can be expressed as follows:

$$DK = DP \sqrt{\pi A}\ FX \tag{3}$$

where DP is the loading parameter and FX is a correction factor. For the solution of equation (1) , DP and R must always be given in tabular listings as functions of the variable T. The correction factor FX can either be given as an analytic function of the crack length A, or listed as point data in tabular form. If tabular form is needed, the MIMIC Program has the capability of generating functions of either one or two variables, such as

$$FX = f(\alpha)$$

or

$$FX = f(\alpha, \beta)$$

where

$$\alpha = \alpha(A), \quad \beta = \beta(A)$$

A general description of the MIMIC Program with operating instructions is given in Reference 2. The card sequence for crack propagation analysis is given in Section III. General input instructions are given in Section IV.

SECTION III

CARD SEQUENCE

The input to the computer program consists of three sets of cards. They are the (1) MIMIC system control cards, (2) function cards and (3) input data cards. These are described in sequence as follows:

1. MIMIC System Control Cards - The set of cards from $SETUP thru $DELETE.

2. Function Cards - These are the program cards and include the following:

   a. Program Name Comment Card

   b. Constant Name Cards

   c. Tabulated Function Definition Cards*

   d. Parameter Name Card - Defines the step functions DP and R

   e. DK Definition Cards

   f. Differential Equation Cards

   g. Program Stop Cards

   h. Header and Output Cards

   i. END Card

3. Input Data Cards - This set of cards immediately follows the program END Card.

   a. Constant Cards

   b. Tabulated Data Cards for Function Generators*

   c. Tabulated Data Cards for Loading Parameters

A complete listing of the program input for two different problems is presented in the Appendix.

---

* Use only if required.

SECTION IV

GENERAL INPUT INSTRUCTIONS

1. MIMIC SYSTEM CONTROL CARDS

The MIMIC program here at WPAFB is maintained on a tape (called MIMIC). The control cards call for the mounting of this tape ($SETUP) and for the calling forth from this tape of the program subroutines ($IBLDR). The subroutine MM02 was modified for this program to change the standard output format. This change requires insertion of the modified Fortran source or binary deck surrounded by $IEDIT control cards in place of the $IBLDR MM02 card in the normal MIMIC system control cards.

The control cards end with a $DATA card to signal the beginning of the function cards and a $DELETE card to delete the MIMIC compiled listing. A complete listing of the cards is shown in TABLE I.

2. FUNCTION CARDS

a. Comment Cards: Any symbol placed in colume 1 results in the entire card being treated as a comment card. The use of these cards is optional in the program.

b. Constant Name Cards: The name of a constant is defined by entering it on a CON card, and its numerical value is given in the data section of the program. As many as six constants may be named on one CON card and as many CON cards as necessary may be used in the program. The format for the Constant Name Cards is as follows:

10	19	73
	CON(A1, C, SN, KC, *, *)	
	CON(*, *, *, *, *, *,)	
	CON(TI, DT1, STOP1)	

The asterisks designate additional constants which may be required for particular problems, such as the plate width B, or an angle α. All specific constants shown are required for every problem.

c. Tabulated Function Definition Cards: Functions generated from tabular data are specified by a CFN (constant function) card. The name of the function (e.g., F) and the number of pairs or triples of points, n, are entered on the CFN cards as follows:

10	19	73
F	CFN(n.)	

The numerical data for the function is given in the data section of the program. The function is used in the program by specifying the array name and the independent variable on a FUN card (See examples in Tables IV).

d. Parameter Name Card: This card defines the load parameters for the program. The parameters are named on a PAR card and their numerical values entered on data cards using the same format as for constants (See examples in Tables II and IV). The basic parameters required for every problem are TF, P, and R. Additional parameters can be specified for solving problems of combined loading, or for problems where constants such as C, SN, and KC change due to environmental conditions.

e. DK Definition Cards: These cards define the expression for DK for the particular problem to be solved. One card should be used to define the expression for DK and additional cards should be used to define the constants and functions in the expression. The format for these cards is shown in the following example from Table IV:

10 Result	19 Expression
PI	3.14159
K	(A/B)*(A/B)
FX	FUN(F, A/B)
DK	DP*SQR(PI*A*FX*FX)

f. Differential Equation Cards:

g. Program Stop Cards:

h. Header and Output Cards:

These cards do not change. See examples in Tables II and IV.

i. END Card:

3. INPUT DATA CARDS

Input format for these cards is given in Reference 2. Examples for two different problems are shown in Tables II and IV. As the examples indicate, the input requirements for these cards are that numerical values must be entered in the same order as the constants or parameters on the CON, CF, or PAR cards. The first number must be entered in columns 1-12, the second in columns 13-24, the third in columns 25-36, the fourth in columns 37-48, the fifth in columns 49-60, and the sixth in columns 61-72. Finally, the numbers must be written in floating point form, that is, a number of digits with a decimal point somewhere in the number.

REFERENCES

1. R. G. Forman, V. E. Kearney, and R. M. Engle, "Numerical Analysis of Crack Propagation in Cyclic-Loaded Structures", ASME Paper No. 66-WA/Met-4.

2. MIMIC - A Digital Simulator Program, SESCA Internal Memo 65-12, Wright-Patterson Air Force Base, Ohio, May 1965.

3. Paul C. Paris and George C. Sih, "Stress Analysis of Cracks", Fracture Toughness Testing and Its Applications, ASTM STP 381.

APPENDIX

1. Sample Problem of Griffith Crack in a Finite Width Plate

   a. Problem Description: See Figure 1.

   b. Load Spectrum: See Figure 3.

   c. Listing of Data Input: See Table II.

   d. Output of Results: See Table III.

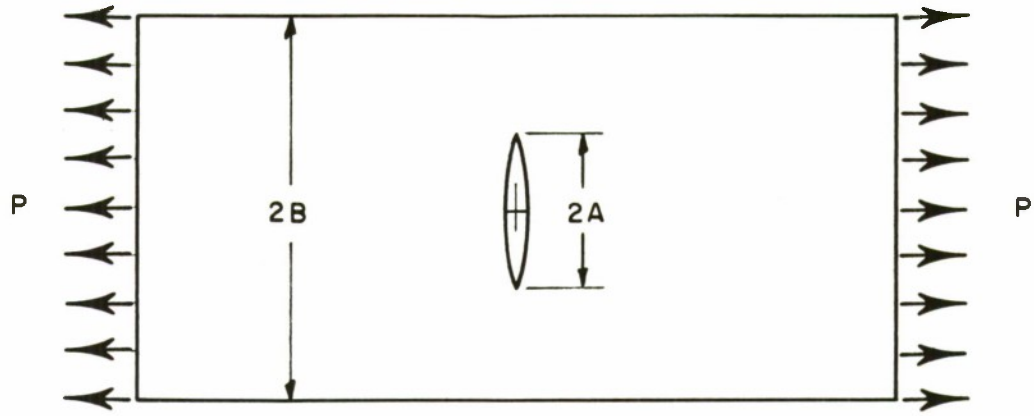
2. Sample Problem of Crack Emanating from a Circular Hole

   a. Problem Description: See Figure 2.

   b. Load Spectrum: See Figure 3.

   c. Listing of Data Input: See Table IV.

   d. Output of Results: See Table V.



$$DK = DP\sqrt{\pi A \beta^2} \quad \text{(from Reference 1)}$$

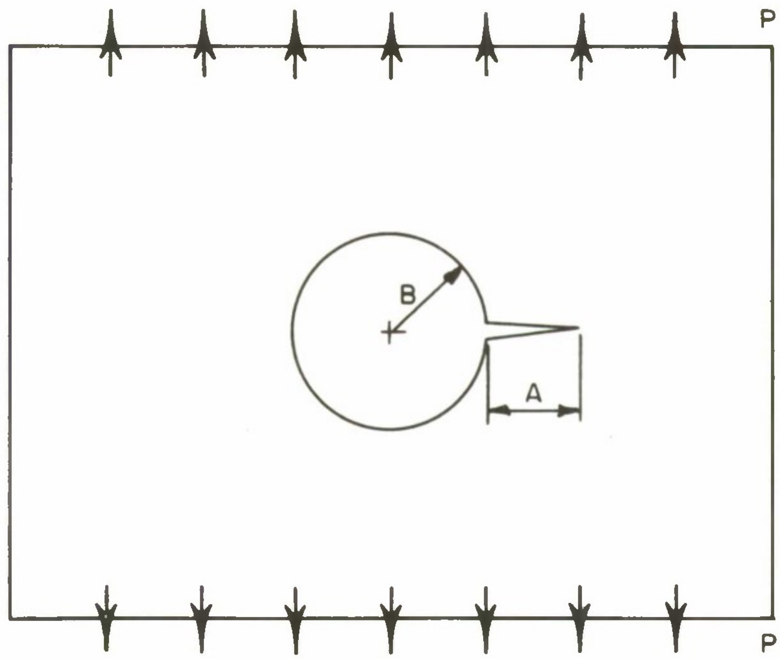
where

$$\beta^2 = 1 + 1.18968K^2 + 1.30162K^4 + 1.36502K^6 + 1.37394K^8 + 1.47638K^{10}$$

and

$$K = A/B$$

Figure 1. Griffith Crack in a Finite Width Plate

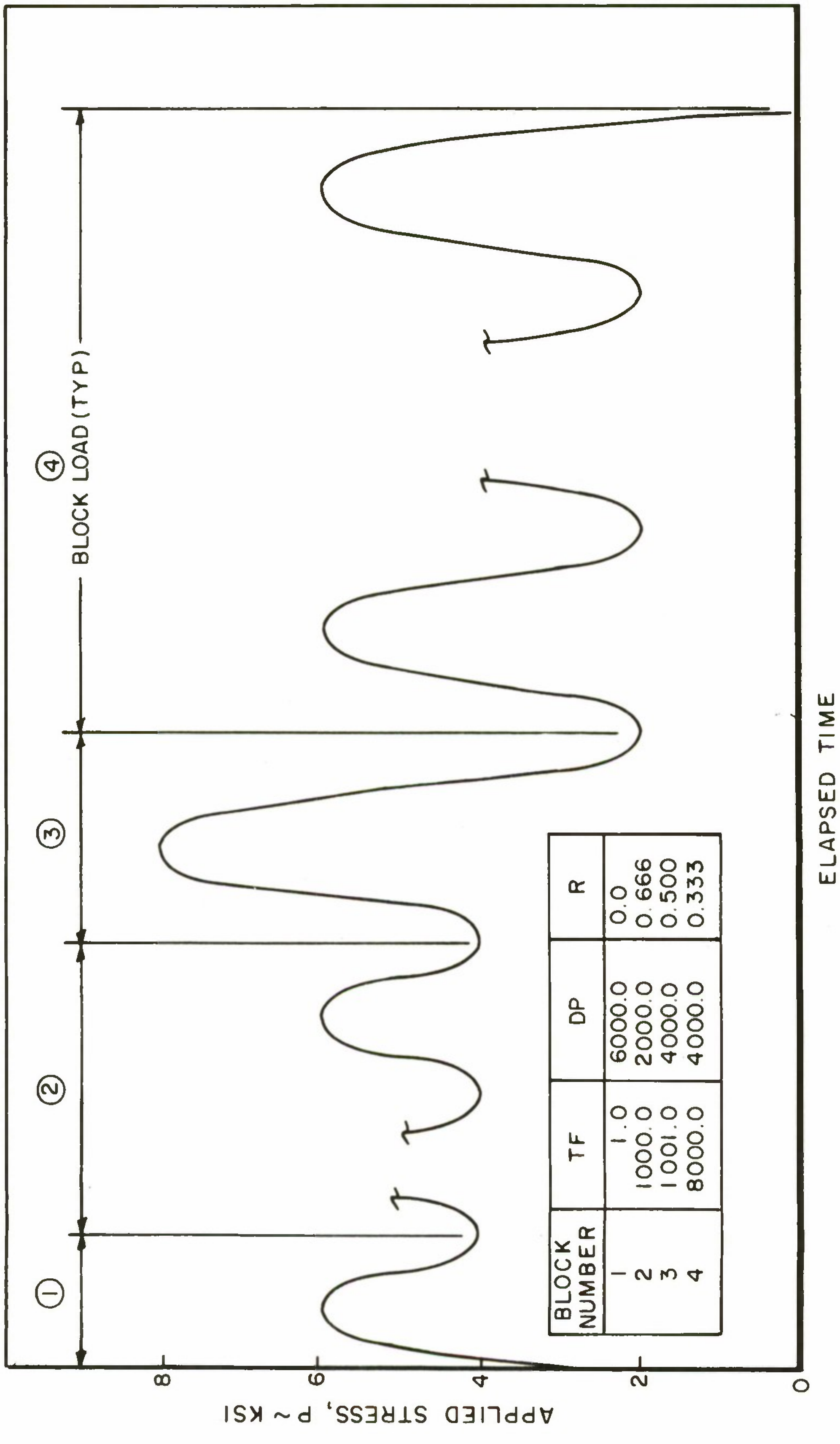


$$DK = DP\sqrt{\pi A}\ FX \quad \text{(From Reference 3)}$$

where point values of FX are as follows:

A/B	FX
0.0	3.39
0.10	2.73
0.20	2.30
0.30	2.04
0.40	1.86
0.50	1.73
0.60	1.64
0.80	1.47
1.0	1.37
1.5	1.18
2.0	1.06
3.0	0.94
5.0	0.81
10.0	0.75
∞	0.707

Figure 2. Crack Emanating from a Circular Hole in a Sheet



BLOCK NUMBER	TF	DP	R
1	1.0	6000.0	0.0
2	1000.0	2000.0	0.666
3	1001.0	4000.0	0.500
4	8000.0	4000.0	0.333

Figure 3. Description of Cyclic Loads for a Sample Problem

TABLE I

LISTING OF INPUT CARDS

```
$SETUP LB4       MIMIC,NORING
$ASSIGN          SYSLB4
$IBJOB MIMIC     FIOCS
$IEDIT           SYSLB4,SCHF1
$IBLDR MMC1
$IEDIT
$IBFTC MMC2      XR7
      SUBROUTINE MIMEX                                                  MM020010
C                                                                       MM020020
C**** EXECUTION PROGRAM                                                 MM020030
C                                                                       MM020040
      DIMENSION P(95),R(2500),S(2500),BCD(10,900),FF(9100)             MM020050
      COMMON P,R,S,FF,IOUT,IPAR,INOUT,IHDR,IFIN,IEND,NPAR,              MM020060
     C          DUMMY(3),IPC,IS,DUMMY1                                  MM020070
      EQUIVALENCE (BCD,FF(101))                                         MM020080
      NRUN=0                                                            MM020090
      INOUT=99                                                          MM020100
      CALL MIMIO(A,B,C,D,E,G)                                           MM020110
C                                                                       MM020120
C**** PROGRAM EXECUTION CONTROL SWITCHES                                MM020130
C                                                                       MM020140
C     IEND=0 NOT END OF RUN                                             MM020150
C         =1 END OF RUN                                                 MM020160
C     IPAR=0 DO NOT READ PARAMETERS                                     MM020170
C         =1 READ PARAMETERS                                            MM020180
C     IOUT=0 DO NOT WRITE OUTPUT                                        MM020190
C         =1 WRITE OUTPUT                                               MM020200
C     IFIN=0 DO NOT TEST FINISH STATEMENTS                              MM020210
C         =1 TEST FINISH STATEMENTS                                     MM020220
C     IHDR=0 DO NOT WRITE HEADERS                                       MM020230
C         =1 WRITE HEADERS                                              MM020240
C     NPAR=0 NO PARAMETERS (ONE RUN)                                    MM020250
C         =1 PARAMETERS (ONE OR MORE RUNS)                              MM020260
C                                                                       MM020270
C**** SET FOR READING INPUT DATA                                        MM020280
C                                                                       MM020290
  100 NRUN=NRUN+1                                                       MM020300
      IPAR=1                                                            MM020310
      PRINT 1,NRUN                                                      MM020320
      IEND=0                                                            MM020330
      IOUT=0                                                            MM020340
      IFIN=0                                                            MM020350
      IHDR=0                                                            MM020360
      R(1)=0.                                                           MM020370
C     WRITE(6,2)                                                        MM020380
      CALL F                                                            MM020390
      IPAR=0                                                            MM020400
      CALL F                                                            MM020410
C**** SET FOR HEADING, OUTPUT, TESTING END OF RUN                       MM020420
```

TABLE I (Continued)

LISTING OF INPUT CARDS

```
      IHDR=1                                                            MM020430
  200 IFIN=1                                                            MM020440
      IOUT=1                                                            MM020450
      CALL F                                                            MM020460
      IHDR=0                                                            MM020470
      IFIN=0                                                            MM020480
      IOUT=0                                                            MM020490
C**** TEST FOR END OF RUN                                               MM020500
      IF(IEND.NE.0) GO TO 300                                           MM020510
C                                                                       MM020520
C**** INTEGRATE                                                         MM020530
C                                                                       MM020540
      CALL MIMIN                                                        MM020550
      GO TO 200                                                         MM020560
C                                                                       MM020570
C**** TEST FOR FURTHER RUNS                                             MM020580
C                                                                       MM020590
  300 IF(IPC.EQ.1) CALL MIMLT                                           MM020600
      IF(NPAR.NE.0) GO TO 100                                           MM020610
      RETURN                                                            MM020620
    1 FORMAT(11H BEGIN RUN ,I4)                                         MM020630
    2 FORMAT(1H1)                                                       MM020640
      END                                                               MM020650
$IEDIT         SYSLB4,SCHF1
$IBLDR MM03
$IBLDR MM04
$IBLDR MM05
$IBLDR MM06
$IBLDR MM07
$IBLDR MM08
$IBLDR MM09
$IBLDR MM10
$IBLDR MM11
$IBLDR MM12
$IBLDR MM13
$IBLDR MM14
$IBLDR MM15
$IBLDR MM16
$IBLDR MM17
$IBLDR MM18
$IBLDR MM19
$IBLDR MM95
$IBLDR MM96
$IBLDR MM97
$IBLDR MM98
$IBLDR MM99
$IEDIT
$DATA
```

↑

Data Input (See Tables II and IV)

↓

$EOF

TABLE II

SAMPLE PROBLEM OF GRIFFITH CRACK IN A FINITE WIDTH PLATE, LISTING OF DATA INPUT

```
$DATA
C GRIFFITH CRACK  IN FINITE WIDTH PLATE
$DELETE
                         CON(AI,C,SN,KC,B)
                         CON(TI,DT1,STOP1)
C   STOP1 IS A CONTROL CONSTANT WHICH WILL STOP THE PROGRAM AFTER
C   DENOM HAS BECOME NEGATIVE.
                         PAR(TF,DP,R)
              PI         3.14159
              DTMIN      1.0
              K          (A/B)*(A/B)
              BETA1      1.0+1.18968*K+1.30162*K*K
              BETA2      K*K*K*(1.36502+1.37394*K+1.47638*K*K)
              B2         BETA1 + BETA2
              DK         DP*SQR(PI*ABS(A)*B2)
              NUMER      EXP(SN,DK*EXP(1./SN,C))
              DENOM      (1.-R)*KC-DK



              IDA        NUMER/DENOM
              A          INT(IDA,AI)
              DT         FSW(TI+T+DT1-TF,DT1,DT1,TF-TI-T)
  STOP        STOP1      FSW(DENOM,-1.0,-1.0,STOP1)
              STOP       IOR(FIN(TI+T,TF),FIN(0.0,STOP1),FIN(0.0,DENOM))
  STOP        AI         A
  STOP        TI         TF
              LCV        FSW(STOP1,FALSE,FALSE,TRUE)
  LCV                    HDR(T,A,R,DP,DENOM)
  LCV                    OUT(TI+T,A,R,DP,DENOM)
                         END
1.25          5.E-13          3.0         68000.       10.
0.0           1000.           1.0
1.0           6000.0          0.0
1000.0        2000.0          0.666
1001.0        4000.0          0.500
8000.0        4000.0          0.333
$EOF
```

TABLE III

SAMPLE PROBLEM OF GRIFFITH CRACK IN A FINITE WIDTH PLATE, OUTPUT OF RESULTS

```
                    ***MIMIC SOURCE-LANGUAGE PROGRAM***

C GRIFFITH CRACK IN FINITE WIDTH PLATE
$DELETE
                         CON(AI,C,SN,KC,B)
                         CON(TI,DT1,STOP1)
C   STOP1 IS A CONTROL CONSTANT WHICH WILL STOP THE PROGRAM AFTER
C   DENOM HAS BECOME NEGATIVE.
                         PAR(TF,DP,R)
          PI             3.14159
          DTMIN          1.0
          K              (A/B)*(A/B)
          BETA1          1.0+1.18968*K+1.30162*K*K
          BETA2          K*K*K*(1.36502+1.37394*K+1.47638*K*K)
          B2             BETA1 + BETA2
          DK             DP*SQR(PI*ABS(A)*B2)
          NUMER          EXP(SN,DK*EXP(1./SN,C))
          DENOM          (1.-R)*KC-DK
          IDA            NUMER/DENOM
          A              INT(IDA,AI)
          DT             FSW(TI+T+DT1-TF,DT1,DT1,TF-TI-T)
 STOP     STOP1          FSW(DENOM,-1.0,-1.0,STOP1)
          STOP           IOR(FIN(TI+T,TF),FIN(0.0,STOP1),FIN(0.0,DENOM))
 STOP     AI             A
 STOP     TI             TF
          LCV            FSW(STOP1,FALSE,FALSE,TRUE)
 LCV                     HDR(T,A,R,DP,DENOM)
 LCV                     OUT(TI+T,A,R,DP,DENOM)
                         END
  AI                C                   SN                  KC                  B
1.25000E 00        5.00000E-13         3.00000E 00         6.80000E 04         1.00000E 01

  TI                DT1                 STOP1
0.                 1.00000E 03         1.00000E 00
```

TABLE III (Continued)

SAMPLE PROBLEM OF GRIFFITH CRACK IN A FINITE WIDTH PLATE, OUTPUT OF RESULTS

```
                              ***EXECUTION***

  TF                DP                R
1.00000E 00       6.00000E 03       0.

  T                 A                 R                 DP                DENOM
0.                1.25000E 00       0.                6.00000E 03       5.59983E 04
1.00000E 00       1.25002E 00       0.                6.00000E 03       5.59982E 04
  TF                DP                R
1.00000E 03       2.00000E 03       6.66000E-01

  T                 A                 R                 DP                DENOM
1.00000E 00       1.25002E 00       6.66000E-01       2.00000E 03       1.87114E 04
1.00000E 03       1.25173E 00       6.66000E-01       2.00000E 03       1.87086E 04
  TF                DP                R
1.00100E 03       4.00000E 03       5.00000E-01

  T                 A                 R                 DP                DENOM
1.00000E 03       1.25173E 00       5.00000E-01       4.00000E 03       2.59931E 04
1.00100E 03       1.25174E 00       5.00000E-01       4.00000E 03       2.59931E 04
  TF                DP                R
8.00000E 03       4.00000E 03       3.33000E-01

  T                 A                 R                 DP                DENOM
1.00100E 03       1.25174E 00       3.33000E-01       4.00000E 03       3.73491E 04
2.00100E 03       1.25864E 00       3.33000E-01       4.00000E 03       3.73262E 04
3.00100E 03       1.26561E 00       3.33000E-01       4.00000E 03       3.73032E 04
4.00100E 03       1.27264E 00       3.33000E-01       4.00000E 03       3.72799E 04
5.00100E 03       1.27974E 00       3.33000E-01       4.00000E 03       3.72566E 04
6.00100E 03       1.28690E 00       3.33000E-01       4.00000E 03       3.72330E 04
7.00100E 03       1.29413E 00       3.33000E-01       4.00000E 03       3.72093E 04
8.00000E 03       1.30142E 00       3.33000E-01       4.00000E 03       3.71855E 04
```

TABLE IV

SAMPLE PROBLEM OF CRACK EMANATING FROM A CIRCULAR HOLE, LISTING OF DATA INPUT

```
$DATA
C CRACK EMANATING FROM A CIRCULAR HOLE.
$DELETE
                    CON(AI,C,SN,KC,B,)
                    CON(TI,DT1,STOP1)
C  STOP1 IS A CONTROL CONSTANT WHICH WILL STOP THE PROGRAM AFTER
C  DENOM HAS BECOME NEGATIVE.
          F         CFN(15.)
C F IS GIVEN IN TABULAR FORM.
                    PAR(TF,DP,R)
          PI        3.14159
          DTMIN     1.0
          K         (A/B)*(A/B)
          FX        FUN(F,A/B)
          DK        DP*SQR(PI*A*FX*FX)
          NUMER     EXP(SN,DK*EXP(1./SN,C))
          DENOM     (1.-R)*KC-DK
          IDA       NUMER/DENOM
          A         INT(IDA,AI)
          DT        FSW(TI+T+DT1-TF,DT1,DT1,TF-TI-T)
 STOP     STOP1     FSW(DENOM,-1.0,-1.0,STOP1)
          STOP      IOR(FIN(TI+T,TF),FIN(0.0,STOP1),FIN(0.0,DENOM))
 STOP     AI        A
 STOP     TI        TF
          LCV       FSW(STOP1,FALSE,FALSE,TRUE)
 LCV                HDR(T,A,R,DP,DENOM)
 LCV                OUT(TI+T,A,R,DP,DENOM)
                    END
1.0         5.0E-13     3.0         68000.0     0.25
0.0         1000.       1.0
  0.0       3.39
  0.10      2.73
  0.20      2.30
  0.30      2.04
  0.40      1.86
  0.50      1.73
  0.60      1.64
  0.80      1.47
  1.0       1.37
  1.5       1.18
  2.0       1.06
  3.0       0.94
  5.0       0.81
 10.0       0.75
100.0       0.707
1.0         6000.0      0.0
1000.0      2000.0      0.666
1001.0      4000.0      0.500
8000.0      4000.0      0.333
$EOF
```

TABLE V

SAMPLE PROBLEM OF CRACK EMANATING FROM A CIRCULAR HOLE, OUTPUT OF RESULTS

```
                  ***MIMIC SOURCE-LANGUAGE PROGRAM***

C CRACK EMANATING FROM A CIRCULAR HOLE.
$DELETE
                        CON(AI,C,SN,KC,B,)
                        CON(TI,DT1,STOP1)
C  STOP1 IS A CONTROL CONSTANT WHICH WILL STOP THE PROGRAM AFTER
C  DENOM HAS BECOME NEGATIVE.
           F            CFN(15.)
C F IS GIVEN IN TABULAR FORM.
                        PAR(TF,DP,R)
           PI           3.14159
           DTMIN        1.0
           K            (A/B)*(A/B)
           FX           FUN(F,A/B)
           DK           DP*SQR(PI*A*FX*FX)
           NUMER        EXP(SN,DK*EXP(1./SN,C))
           DENOM        (1.-R)*KC-DK
           IDA          NUMER/DENOM
           A            INT(IDA,AI)
           DT           FSW(TI+T+DT1-TF,DT1,DT1,TF-TI-T)
 STOP      STOP1        FSW(DENOM,-1.0,-1.0,STOP1)
           STOP         IOR(FIN(TI+T,TF),FIN(0.0,STOP1),FIN(0.0,DENOM))
 STOP      AI           A
 STOP      TI           TF
           LCV          FSW(STOP1,FALSE,FALSE,TRUE)
 LCV                    HDR(T,A,R,DP,DENOM)
 LCV                    OUT(TI+T,A,R,DP,DENOM)
                        END
```

TABLE V (Continued)

SAMPLE PROBLEM OF A CRACK EMANATING FROM A CIRCULAR HOLE, OUTPUT OF RESULTS

AI	C	SN	KC	B
1.00000E 00	5.0000CE-13	3.00000E 00	6.80000E 04	2.50000E-01

II	DT1	STOP1
0.	1.0000CE 03	1.00000E 00

15.	F	
0.	3.39000E 0C	-0.
1.00000E-01	2.73000E 00	-0.
2.00000E-01	2.30000E 0C	-0.
3.00000E-01	2.040C0E 0C	-0.
4.00000E-01	1.860C0E 0C	-0.
5.00000E-01	1.730C0E 0C	-0.
6.00000E-01	1.640C0E 0C	-0.
8.00000E-01	1.470C0E 0C	-0.
1.00000E 00	1.37000E 00	-0.
1.50000E 00	1.18000E 0C	-0.
2.00000E 00	1.060C0E 0C	-0.
3.00000E 00	9.40000E-01	-0.
5.00000E 00	8.10000E-01	-0.
1.00000E 01	7.50000E-01	-0.
1.00000E 02	7.07000E-01	-0.

TABLE V (Continued)

SAMPLE PROBLEM OF CRACK EMANATING FROM A CIRCULAR HOLE, OUTPUT OF RESULTS

```
                                ***EXECUTION***

   TF                  DP                  R
1.00000E 00         6.00000E 03         0.

   T                   A                   R                   DP                  DENOM
0.                  1.00000E 00         0.                  6.00000E 03         5.86948E 04
1.00000E 00         1.00001E 00         0.                  6.00000E 03         5.86947E 04
   TF                  DP                  R
1.00000E 03         2.00000E 03         6.66000E-01

   T                   A                   R                   DP                  DENOM
1.00000E 00         1.00001E 00         6.66000E-01         2.00000E 03         1.96102E 04
1.00000E 03         1.00077E 00         6.66000E-01         2.00000E 03         1.96098E 04
   TF                  DP                  R
1.00100E 03         4.00000E 03         5.00000E-01

   T                   A                   R                   DP                  DENOM
1.00000E 03         1.00077E 00         5.00000E-01         4.00000E 03         2.77955E 04
1.00100E 03         1.00077E 00         5.00000E-01         4.00000E 03         2.77955E 04
   TF                  DP                  R
8.00000E 03         4.00000E 03         3.33000E-01

   T                   A                   R                   DP                  DENOM
1.00100E 03         1.00077E 00         3.33000E-01         4.00000E 03         3.91515E 04
2.00100E 03         1.00382E 00         3.33000E-01         4.00000E 03         3.91477E 04
3.00100E 03         1.00688E 00         3.33000E-01         4.00000E 03         3.91439E 04
4.00100E 03         1.00995E 00         3.33000E-01         4.00000E 03         3.91402E 04
5.00100E 03         1.01302E 00         3.33000E-01         4.00000E 03         3.91364E 04
6.00100E 03         1.01610E 00         3.33000E-01         4.00000E 03         3.91327E 04
7.00100E 03         1.01918E 00         3.33000E-01         4.00000E 03         3.91290E 04
8.00000E 03         1.02226E 00         3.33000E-01         4.00000E 03         3.91253E 04
```

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4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

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13. ABSTRACT

This report presents a detailed description of a computer program for the crack propagation analysis of cyclic loaded structures. The computer program calculates crack growth for both uniform and non-uniform cyclic loading and also caluclates the number of load cycles to cause crack growth instability. Instructions for use of the program and two illustrative analysis problems are presented.

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